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ROUGH SURFACE BACKSCATTER

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ROUGH SURFACE BACKSCATTER

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Science Applications International Corporation

Prepared by
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ROUGH SURFACE BACKSCATTER

The intent of this contract was to further analyze some model computations of backscattering strength which were done in summer of 1987. This computational model (equation (1) below) tracked (with a 3-5 dB difference) the Chapman-Harris-Scott empirical model for backscattering over a wide range of parameters, (150-1200 Hz, 10-45 deg. grazing, and 10-40 knots winds). However, the computation was not properly windowed, and when a suitable window was introduced, the computational backscattering strength agreed very closely with the standard perturbational model for backscattering (a model valid only for small values of the Rayleigh parameter).

This result is in itself rather surprising, as the integral involved (derived via a Kirchoff approximation) has the form

$$SS_{ka} = q_z^2 \iint_{S_0} d^2\rho \; e^{-q_\perp \cdot \rho} A(\rho) [e^{-q^2{}_z \sigma^2 (1-W(\rho)]} - e^{-q_z{}^2 \sigma^2}] / (4\pi)^2 \tag{1}$$

where $q_z = 2k \sin(\theta)$, k = acoustic wave number, θ = grazing angle relative to mean surface, $q_\perp = (-2k\cos(\theta),\ 0)$, $\rho = (\rho_x, \rho_y)$, S_0 = illuminated area of surface, $A(\rho)$ = windowing function (e.g., raised cosine, etc.), σ^2 = surface height variance, and $W(\rho)$ = normalized surface autocorrelation function. The computed result is very nearly independent of S_0 and $A(\rho)$, for suitably tapered windows,

Clearly for $\sigma^2 q_z^2 << 1$, the above integral reduces to the perturbation result

$$SS_{pert} = q_z{}^4 F(q_\perp)/4 \tag{2}$$

where F(K) = the surface power spectrum. But for $\sigma^2 q_z^2 >> 1$, it is by no means obvious why $SS_{ka} \cong SS_{pert}$, (within 2-3 dB). Note that for 1200 Hz, 45 deg, and 40 knots, $\sigma^2 q_z^2 = 50$.

As is well known, the SS_{pert} scattering model depends only weakly on frequency and wind speed, (using the Toba or Donelan-Pierson spectrum). This is in contrast to many data sets, which exhibit a fairly strong dependence upon both parameters. Due to the computational results cited above, it follows that the SS_{ka} model has this same weak dependence.

It should be noted that both models (1) and (2) are incorrect for large Rayleigh parameter. SS_{pert} is the first term in an expansion in the Rayleigh parameter, and is only valid for small values, where the higher order terms are negligible.

The SS_{ka} model, and in fact all analytical scattering models that use integrals of $\partial P_{bdry}/\partial n$ (the normal derivative of the pressure field in the boundary), are inaccurate, because these models must assume some functional representation for $\partial P_{bdry}/\partial n$, in general unknown. Recall that the boundary pressure is required to be zero on the free boundary. The Kirchoff approximation assumes the field in the boundary is that due to the source and an image source in the reflected region. But this field is only zero on the flat mean surface, not on the actual ocean surface itself. This approximation implies that $\partial P_{bdry}/\partial n = 2\partial P_{inc}/\partial n$. Since modifying the boundary field to zero may well require large changes in the derivatives, there is no way of assessing the error in this approximation.

The Kirchoff approximation may also be thought of as the approximate solution of an integral equation satisfied by $\partial P_{bdry}/\partial n$, of the form

$$[I-T][\partial P_{bdry}/\partial n] = 2\partial P_{inc}/\partial n$$

where T is an integral operator over S_0.

Now $[I-T]^{-1} = \Sigma T^n$, $0 \leq n < \infty$, if $||T|| << 1$, over some function space. If the Neumann series converges, then the Kirchoff approximation is equivalent to the approximation $[I-T]^{-1} \cong I$. But for large Rayleigh parameter, i) it is not known if the series converges; and ii) no error bounds are known on the terms $T^n(\partial P_{bdry}/\partial n)$.

With respect to obtaining a second order theory, Winebrenner in his thesis uses a Rytov method of partial summation to obtain a scattering model that includes second order terms in the phase term. But Winebrenner also shows that his model reduces to SS_{pert} for small Rayleigh parameter, and to SS_{ka} for large values. Since the computational model shows that these two models agree for the ocean surface, there is no reason to believe Winebrenner's model gives anything new for the ocean surface.

Another class of theoretical scattering models are the composite surface models, SS_{cs}, where the scattering is regarded as diffraction from a small surface (high wavenumber), riding on a large surface (low wavenumber).

Since one rationale for introducing SS_{cs} is to more accurately evaluate the integrals in SS_{ka}, the recent computations have reduced the need for such an approach. Other derivations of SS_{cs} are ad hoc, and do not begin with SS_{ka},

but the resulting SS_{cs} model agrees with those which begin with SS_{ka}.

However, if one does introduce a large and a small surface, separated by some dividing wave number K_D, the result is that in a number of the standard SS_{cs} (see Brown, Bahar and Barrick, McDaniels, the NRL model, etc.), the dominant effect is the introduction of an "effective" grazing angle, i.e., θ is replaced by $\theta + \theta_{tilt}$, where $\tan(\theta_{tilt})$ = the rms slope of the large surface.

This model does produce more wind speed dependence and frequency dependence, depending upon how one chooses the divider K_D, but not enough of an increase to adequately model the data.

To add to the above, a new composite surface model has been developed by the San Diego group (Dashen-details not available), which chooses K_D very small, so that the tilt of the large surface is negligible. Of course, in this case, $SS_{cs} \cong SS_{pert}$ once more.

Surveying all the existing scattering models, one is forced to the conclusion that there is no reason to conclude that one of them is accurate for large Rayleigh parameters.

Due to the above difficulties with surface scattering models, and also the problem with zero Doppler backscattering, there has been a recent renewal of interest by DARPA in bubble scattering models. The JASON committee, in the summer of 1987, considered and rejected a bubble model based upon scattering from bubbles with diameters in the micron range.

In the spring and summer of 1988, consideration was given to scattering from sausage shaped bubbles (several centimeters in diameter) which detach from the base of capillary waves as the wind increases, (see Toba, Longuet-Higgins). No conclusions are available concerning this model, as apparently too many of the relevant model parameters are unknown, (e.g., density, duration, depth of the bubble layer below the surface, etc.).

More recently, attention is being paid to a third bubble model, consisting of large foam bubbles, (meter diameter) which slide down the face of large waves beneath the surface. As of this writing, the results of this bubble model are also unknown, again most probably due to the lack of knowledge of the governing parameters. Because of this uncertainty, it may be some time before conclusions are obtained.

Even if ultimately some bubble scattering model successfully explains the data (most particularly zero Doppler scattering), an accurate surface scatter model now would certainly clarify the need for additional scattering mechanisms, such as bubbles, in order to satisfactorily model the data.

Accordingly, during the last stages of this contract a new computationally intensive approach towards an exact scattering model was begun. Using a computer simulated ocean surface, an exact (to 2-3 place accuracy, or as required) scattering strength for that surface is obtained. No analytical assumptions regarding $\partial P_{bdry}/\partial n$ are made, and an error criterion is developed to evaluate the accuracy of the computed scattering strength.

Performing this calculation for N surfaces (N = 30, 40?) will give enough data to estimate the ensemble averaged scattering strength (the usual notion of scattering strength, the ensemble average of the 2nd moment of pressure). This will be the first valid estimate of scattering strength for large Rayleigh parameter.

In addition, these computations will also provide estimates of the variance of scattering strength (from a theoretical point of view, this requires the ensemble average of a 4th moment of pressure). This last statistic should be a valuable addition to our knowledge of the surface scattering problem.

Major portions of the coding for this approach have been completed, and preliminary results indicate the theoretical approach is correct, and the computations outlined above are feasible.

Because this method is implemented on a computer, it is flexible, and, for example, rather than using a finite Fourier series as a model for the ocean surface, could easily be modified to include in the surface model the large bubbles considered in the third bubble model.

It also seems very likely that this approach can be modified to address scattering from a rigid boundary, i.e., the rough ocean basement. As more accurate spectral models of the ocean basement are becoming available, computer simulated basement surfaces can more accurately model the actual surface. And the above computational model, extended to the case of a rigid boundary, could provide insight into such questions as the anomalous time spreads observed in scattering from the rough basement.